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FULL LENGTH ARTICLE

An Improved Approach for Sustainable Risk Management Practices in Modern Businesses

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ABSTRACT

The complexity of the business environment, which is shaped by dynamic economic, environmental, and social factors, makes it more important for companies to develop sustainable risk management practices. This research proposes a novel approach that combines traditional methods with modern machine learning techniques in response to the complex challenges faced by contemporary businesses in balancing risk and sustainability. Our study uses a public bank loan default dataset as a case study to address missing data systematically through robust imputation mechanisms and transform categorical variables using feature encoding. Spearman correlation analysis helps us understand complex variable relationships and guides subsequent feature selection. The decision tree classifier, a powerful machine learning algorithm known for its interpretability, is applied to identify key factors contributing to risk assessment. The hierarchical structure of the decision tree not only reveals important variables but also provides an explicit representation of the decision-making process. ROC curve analysis shows how well our predictive model can differentiate potential loan defaults.

Keywords: Sustainability ▪ Modern business ▪ Risk mitigation ▪ Corporate sustainability ▪ Economic sustainability ▪ Long-term risk planning ▪ Risk management

1. INTRODUCTION

In the current business environment, sustainable risk management practices have become a necessity for organizations as they navigate through an increasingly complex and interconnected global landscape. Traditionally, risk management has been mainly focused on financial and operational aspects. However, with the growing awareness of environmental, social, and governance (ESG) factors, the paradigm is shifting towards a more holistic approach [1, 2, 3]. Over the past decade, businesses have faced heightened scrutiny regarding their impact on the environment, society, and overall sustainability. This shift necessitates a comprehensive understanding of the evolution of risk management strategies, considering the interplay of economic, social, and environmental dimensions [4, 5]. However, there is a significant gap in literature regarding sustainable risk management practices that are suitable for modern businesses. The existing research tends to be fragmented, with limited integration of sustainability considerations into risk management frameworks [6].

Moreover, there is no comprehensive analysis of the specific challenges and opportunities that modern businesses face in implementing sustainable risk management. It is important to fill this gap so as to develop a better understanding of the complexities involved and provide practical advice for companies seeking to improve their resilience while adhering to sustainability principles [7, 8]. The motivation behind this work arises from the need to address these research gaps and contributes to the ongoing debate on sustainable risk management. As businesses grapple with climate change impacts,

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social inequality, and changing regulatory environments, the demand for strong and flexible risk management strategies has never been more urgent [9, 10].

This study aims at developing a comprehensive framework that captures the multiple challenges faced by contemporary organizations at the intersection of sustainability and risk management. The aim is to enable companies to manage risks proactively while promoting sustainability through ethical, environmental, and social responsibility in their operations [11]. The importance of this research is underscored by understanding the historical context, identifying research gaps, and explaining the motivation behind this study. This work aims to contribute to academic knowledge and provide practical insights for businesses that are trying to incorporate sustainability into their risk management practices [12]. The results are expected to help organizational leaders, policy makers, and researchers in developing holistic strategies that address both conventional and emerging risks within a sustainable framework. In this way, the study seeks to enhance the debate on sustainable business practices that foster resilience, accountability, and long-term survival in an ever-changing business environment.

2. PROPOSED APPROACH

This section outlines a new and integrated approach to sustainable risk management practices in response to the gaps identified in the existing literature and the changing landscape of modern business challenges. It provides an elaborate explanation of the key components, methodologies, and theoretical underpinnings that make up the proposed approach, thus offering a guide for organizations that want to strengthen their risk management strategies while embracing sustainability as a core business principle [13].

The first step in our proposed approach is a careful data imputation mechanism for handling missing values within the bank loan default dataset. Missing data can introduce biases and compromise the integrity of subsequent analyses. We use robust imputation methods such as mean imputation, which is widely used, or more advanced techniques like k-nearest neighbors' imputation to ensure that data quality is maintained while preserving the overall structure of the dataset [14].

After imputation, we use feature encoding techniques to convert categorical variables into a form that is suitable for our analysis. This step is important to enable the integration of categorical data into the predictive model. Some common methods include one-hot encoding or label encoding, each having its own advantages depending on the nature of the categorical variables. By converting categorical features into numerical representations, we allow for a more comprehensive analysis while retaining the essential information contained in these variables.

Spearman correlation analysis leads our exploratory data analysis; it is a non-parametric method used to evaluate monotonic relationships among variables. Unlike traditional correlation coefficients, Spearman correlation can capture nonlinear associations. This analysis helps us to understand the strength and direction of relationships within the dataset, identify potential multicollinearity concerns, and inform subsequent feature selection steps [15, 16, 17].

Additionally, the core of our predictive modeling is based on the use of a decision tree classifier, which is a powerful machine learning algorithm known for its interpretability and versatility. Decision trees divide the feature space into regions based on important variables, making it easier to identify decision rules for predicting loan defaults. The hierarchical structure of the algorithm is consistent with our sustainable risk management framework, which makes it possible to see clearly what factors contribute to prediction. This step represents the climax of our proposed approach, where we employ machine learning to improve risk assessment accuracy in a sustainable business context [18, 19].

3. RESULTS AND DISCUSSION

The empirical findings of our research on the integration of sustainable risk management practices in modern businesses are revealed in this section. A public case study was used in this research, which focused on bank loan default data. We chose this case study because it had a lot of information and was relevant to the wider discussion about sustainable risk management in the financial sector. The dataset used for this study was obtained from reputable public repositories and contains a wide range of variables that can be used to examine different aspects of risk assessment and management within banking.

Figure 1 shows a missing value plot, which is an important part of our data analysis method. Missing value visualization is one way to ensure that the dataset we used for our study is complete and accurate. This plot gives an overview of how missingness is distributed across variables, thereby providing insights into possible patterns and guiding subsequent imputation strategies. It helps identify variables with high missingness so that incomplete information can be handled effectively through targeted approaches. This transparency in addressing missing values not only underscores the robustness of our analytical process but also enhances the reliability and interpretability of the subsequent results. This graphical representation serves as a foundational element in our data preprocessing steps, contributing to the overall transparency and rigor of our research methodology.

Table 1 provides a comprehensive summary of missing values for each variable in the bank loan default dataset, giving a detailed account of how much data is missing across the entire dataset. This table is important for researchers and practitioners as it allows them to systematically examine the completeness of individual variables. Table 1 gives an overview of missing values, which makes our data analysis process more transparent and helps us identify variables with higher levels of incompleteness. This careful recording of missing values ensures that subsequent imputation methods are reliable and also helps us understand the quality of the dataset better, thus making our sustainable risk management analysis more robust.

Figure 2 shows a correlation dendrogram that captures the interrelationships among variables in the bank loan default dataset. This dendrogram provides a holistic view of the correlation structure, which helps to identify clusters of variables

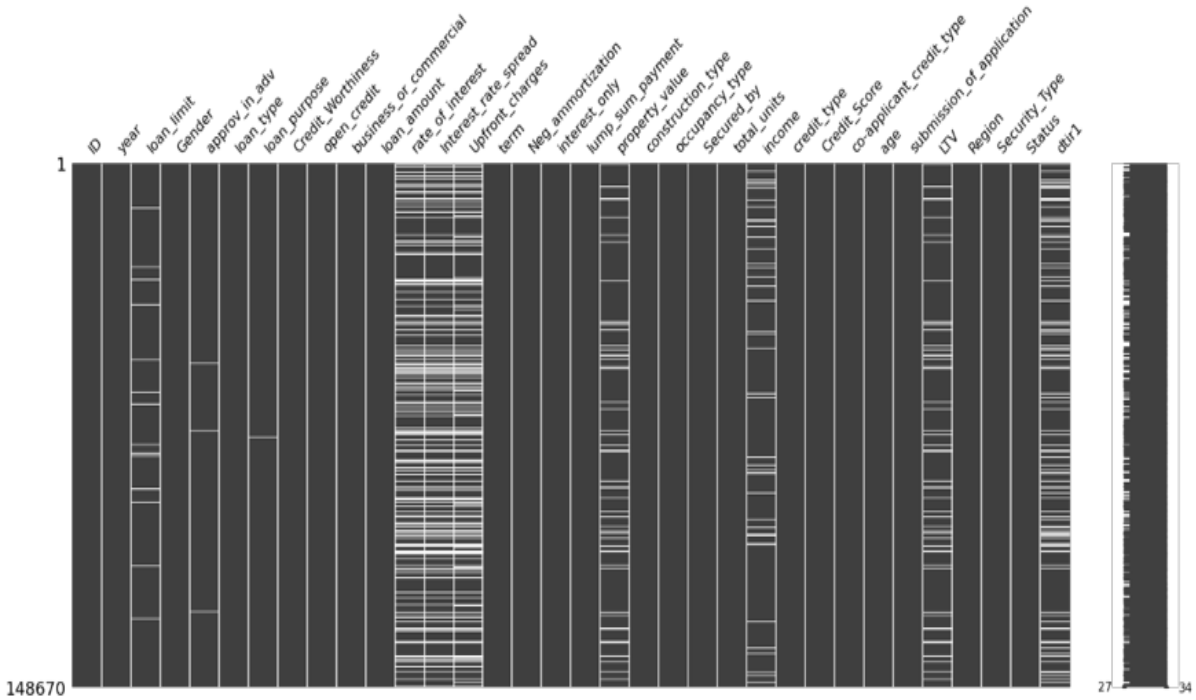


Figure 1. Missing Value Plot—visualization of missing data distribution across variables in the bank loan default dataset.

Table 1. A detailed overview of missing data for each variable in the bank loan default dataset

Column Name	Null Values (%)	Column Name	Null Values (%)
OWN_CAR_AGE	65.99081	FLOORSMIN_MODE	67.84863
EXT_SOURCE_1	56.381073	LANDAREA_MODE	59.37674
APARTMENTS_AVG	50.749729	LIVINGAPARTMENTS_MODE	68.35495
BASEMENTAREA_AVG	58.515956	LIVINGAREA_MODE	50.19333
YEARS_BEGINEXPLUATATION_AVG	48.781019	NONLIVINGAPARTMENTS_MODE	69.43296
YEARS_BUILD_AVG	66.497784	NONLIVINGAREA_MODE	55.17916
COMMONAREA_AVG	69.872297	APARTMENTS_MEDI	50.74973
ELEVATORS_AVG	53.29598	BASEMENTAREA_MEDI	58.51596
ENTRANCES_AVG	50.348768	YEARS_BEGINEXPLUATATION_MEDI	48.78102
FLOORSMAX_AVG	49.760822	YEARS_BUILD_MEDI	66.49778
FLOORSMIN_AVG	67.84863	COMMONAREA_MEDI	69.8723
LANDAREA_AVG	59.376738	ELEVATORS_MEDI	53.29598
LIVINGAPARTMENTS_AVG	68.354953	ENTRANCES_MEDI	50.34877
LIVINGAREA_AVG	50.193326	FLOORSMAX_MEDI	49.76082
NONLIVINGAPARTMENTS_AVG	69.432963	FLOORSMIN_MEDI	67.84863
NONLIVINGAREA_AVG	55.179164	LANDAREA_MEDI	59.37674
APARTMENTS_MODE	50.749729	LIVINGAPARTMENTS_MEDI	68.35495
BASEMENTAREA_MODE	58.515956	LIVINGAREA_MEDI	50.19333
YEARS_BEGINEXPLUATATION_MODE	48.781019	NONLIVINGAPARTMENTS_MEDI	69.43296
YEARS_BUILD_MODE	66.497784	NONLIVINGAREA_MEDI	55.17916
COMMONAREA_MODE	69.872297	FONDKAPREMONT_MODE	68.38617
ELEVATORS_MODE	53.29598	HOUSETYPE_MODE	50.17609
ENTRANCES_MODE	50.348768	TOTALAREA_MODE	48.26852
FLOORSMAX_MODE	49.760822	WALLSMATERIAL_MODE	50.84078

with similar patterns of association. The dendrogram is useful for detecting potential multicollinearity and dependencies within the dataset using hierarchical clustering techniques. This visualization helps to understand complex relationships and informs subsequent feature selection or dimensionality reduction steps in our sustainable risk management analysis. The correlation dendrogram is an important tool for understanding how variables are interconnected, thus enhancing the robustness and interpretability of our analytical framework.

Table 2 provides a detailed presentation of the Variance Inflation Factor (VIF) for various features within the bank loan default dataset. The VIF analysis is a crucial step in assessing multicollinearity, offering insights into the potential inflation of variance due to intercorrelations among predictor variables. By quantifying the extent of multicollinearity, this table as-sists in identifying features with high VIF scores, indicative of heightened correlation with other variables. Through this systematic examination, we gain a nuanced understanding of the stability and reliability of our regression models in the sustainable risk management analysis. Table 2 thus plays a pivotal role in the diagnostic phase of our methodology, guiding the refinement of our predictive models and ensuring the robustness of our findings in addressing multicollinearity concerns.

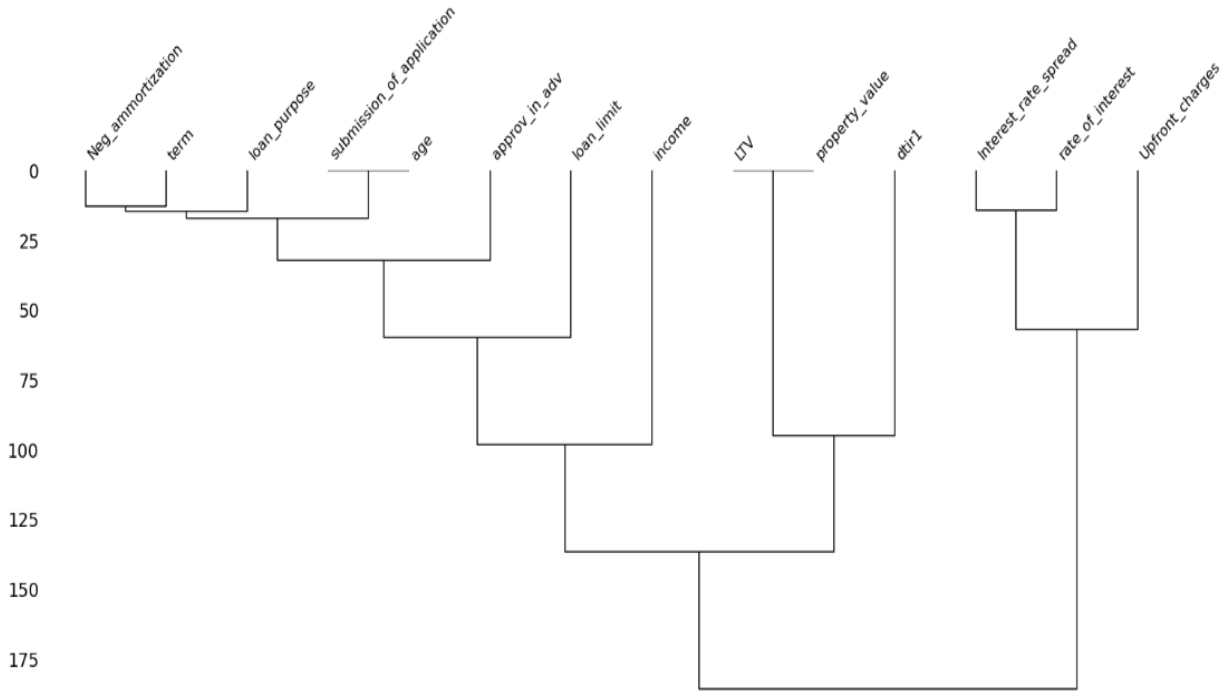


Figure 2. Correlation Dendrogram—hierarchical clustering visualization depicting the interrelationships among variables in the bank loan default dataset.

Table 2. Variance Inflation Factor (VIF) Analysis—comprehensive assessment of multicollinearity for different features in the bank loan default dataset

Feature	VIF	Feature	VIF
DEF_30_CNT_SOCIAL_CIRCLE	4.31	FLAG_DOCUMENT_14_1	1.05
DEF_60_CNT_SOCIAL_CIRCLE	4.27	ORGANIZATION_TYPE_Trade:type4	1.05
FLAG_OWN_REALTY_1	3.47	ORGANIZATION_TYPE_Industry:type13	1.04
FLAG_LAST_APPL_PER_CONTRACT	2.88	NAME_PAYMENT_TYPE_Non-cashfromyouraccount	1.04
NAME_FAMILY_STATUS_Married	2.83	NAME_CASH_LOAN_PURPOSE_Urgentneeds	1.04
NFLAG_LAST_APPL_IN_DAY	2.80	ORGANIZATION_TYPE_SecurityMinistries	1.04
NAME_INCOME_TYPE_Working	2.64	NAME_TYPE_SUITE_y_Other_B	1.04
NAME_PAYMENT_TYPE_XNA	2.00	NAME_CASH_LOAN_PURPOSE_Buyingausedcar	1.04
FLAG_OWN_CAR_1	1.82	AMT_REQ_CREDIT_BUREAU_MON	1.04
WEEKDAY_APPR_PROCESS_START_y_MONDAY	1.82	AMT_REQ_CREDIT_BUREAU_QRT	1.04
WEEKDAY_APPR_PROCESS_START_x_TUESDAY	1.81	AMT_REQ_CREDIT_BUREAU_HOUR	1.04
WEEKDAY_APPR_PROCESS_START_x_MONDAY	1.79	FLAG_DOCUMENT_5_1	1.04
WEEKDAY_APPR_PROCESS_START_x_THURSDAY	1.77	SELLERPLACE_AREA	1.04
CODE_GENDER_M	1.76	AMT_REQ_CREDIT_BUREAU_DAY	1.04
WEEKDAY_APPR_PROCESS_START_y_TUESDAY	1.76	NAME_CASH_LOAN_PURPOSE_Purchaseofelectronicequipment	1.03
WEEKDAY_APPR_PROCESS_START_y_WEDNESDAY	1.76	ORGANIZATION_TYPE_Mobile	1.03
WEEKDAY_APPR_PROCESS_START_x_WEDNESDAY	1.75	ORGANIZATION_TYPE_LegalServices	1.03

Table 2. Variance Inflation Factor (VIF) Analysis—continued

Feature	VIF	Feature	VIF
WEEKDAY_APPR_PROCESS_START_y_THURSDAY	1.74	ORGANIZATION_TYPE_Insurance	1.03
WEEKDAY_APPR_PROCESS_START_y_SATURDAY	1.68	NAME_TYPE_SUITE_y_Other_A	1.03
FLAG_PHONE_1	1.60	FLAG_DOCUMENT_9_1	1.03
DAYS_BIRTH	1.58	FLAG_DOCUMENT_16_1	1.03
WEEKDAY_APPR_PROCESS_START_y_SUNDAY	1.52	NAME_TYPE_SUITE_x_Other_B	1.03
FLAG_WORK_PHONE_1	1.50	NAME_CASH_LOAN_PURPOSE_Carrepairs	1.03
WEEKDAY_APPR_PROCESS_START_x_SATURDAY	1.48	NAME_HOUSING_TYPE_Officeapartment	1.03
NFLAG_INSURED_ON_APPROVAL_1.0	1.41	ORGANIZATION_TYPE_Industry:type1	1.03
HOUR_APPR_PROCESS_START_y	1.27	NAME_SELLER_INDUSTRY_Jewelry	1.02
WEEKDAY_APPR_PROCESS_START_x_SUNDAY	1.27	ORGANIZATION_TYPE_University	1.02
REG_CITY_NOT_LIVE_CITY_1	1.26	NAME_CASH_LOAN_PURPOSE_Medicine	1.02
NAME_INCOME_TYPE_Stateservant	1.25	FLAG_DOCUMENT_13_1	1.02
DAYS_DECISION	1.24	NAME_CASH_LOAN_PURPOSE_Paymentsonotherloans	1.02
HOUR_APPR_PROCESS_START_x	1.23	ORGANIZATION_TYPE_Telecom	1.02
DAYS_REGISTRATION	1.18	ORGANIZATION_TYPE_Cleaning	1.02
REG_REGION_NOT_LIVE_REGION_1	1.18	ORGANIZATION_TYPE_Restaurant	1.02
FLAG_EMAIL_1	1.14	ORGANIZATION_TYPE_Realtor	1.02

Table 2. Variance Inflation Factor (VIF) Analysis—continued

Feature	VIF	Feature	VIF
NAME_CLIENT_TYPE_Refreshed	1.13	ORGANIZATION_TYPE_Industry:type7	1.02
REGION_POPULATION_RELATIVE	1.13	ORGANIZATION_TYPE_Industry:type6	1.02
CHANNEL_TYPE_Contactcenter	1.13	ORGANIZATION_TYPE_Industry:type5	1.02
AMT_REQ_CREDIT_BUREAU_YEAR	1.12	NAME_CLIENT_TYPE_XNA	1.02
NAME_TYPE_SUITE_y_Spouse,partner	1.11	ORGANIZATION_TYPE_Hotel	1.02
DAYS_ID_PUBLISH	1.11	ORGANIZATION_TYPE_Emergency	1.02
DAYS_LAST_PHONE_CHANGE	1.11	NAME_CASH_LOAN_PURPOSE_Journey	1.01
FLAG_DOCUMENT_18_1	1.10	NAME_CASH_LOAN_PURPOSE_Gasification/watersupply	1.01
AMT_ANNUITY_x	1.09	NAME_CASH_LOAN_PURPOSE_Furniture	1.01
NAME_TYPE_SUITE_x_Spouse,partner	1.07	NAME_CASH_LOAN_PURPOSE_Everydayexpenses	1.01
FLAG_DOCUMENT_20_1	1.07	NAME_CASH_LOAN_PURPOSE_Education	1.01
CHANNEL_TYPE_Channelofcorporatesales	1.07	AMT_INCOME_TOTAL	1.01
FLAG_DOCUMENT_11_1	1.07	NAME_CASH_LOAN_PURPOSE_Buyinganewcar	1.01
NAME_TYPE_SUITE_y_Groupofpeople	1.06	NAME_CASH_LOAN_PURPOSE_Buyingahome	1.01
ORGANIZATION_TYPE_Transport:type3	1.05	AMT_REQ_CREDIT_BUREAU_WEEK	1.01
DAYS_FIRST_DUE	1.05	FLAG_DOCUMENT_15_1	1.01

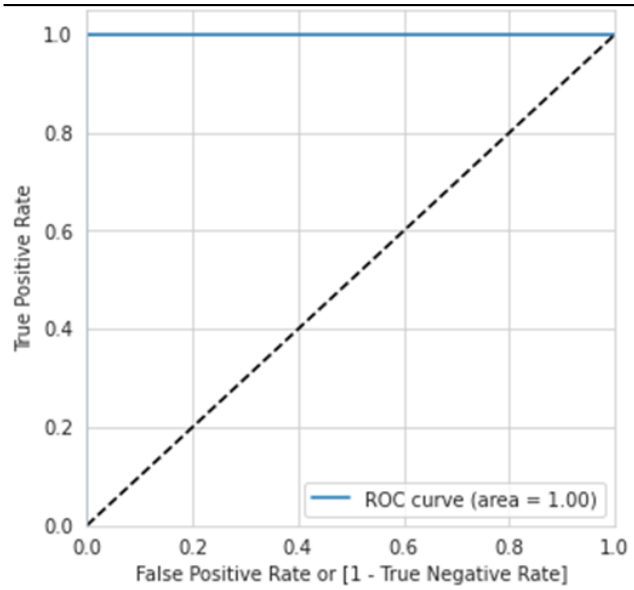


Figure 3. Receiver Operating Characteristic (ROC) Curve—graphical representation illustrating the performance of the predictive model for sustainable risk management in bank loan defaults.

In Figure 3, we introduce the Receiver Operating Characteristic (ROC) curve, a pivotal graphical representation that evaluates the performance of our predictive model in the context of sustainable risk management for bank loan defaults. The ROC curve illustrates the trade-off between true positive rates and false positive rates across varying classification thresholds, offering a comprehensive view of the model's discriminatory power. This graphical analysis serves as a critical tool for assessing the effectiveness of our predictive framework in distinguishing between default and non-default instances. Through a detailed examination of the ROC curve, we gain insights into the model's sensitivity and specificity, crucial metrics in the evaluation of its predictive accuracy. The ensuing discussion delves into the nuanced implications of the ROC curve results, shedding light on the model's capability to inform sustainable risk management decisions in the financial sector.

4. CONCLUSION

This research endeavors to contribute to the evolving landscape of sustainable risk management practices in modern businesses. Through a meticulous exploration of a public bank loan default dataset, we proposed a comprehensive approach encompassing data imputation, feature encoding, Spearman correlation analysis, and the application of a decision tree classifier. Our findings shed light on the intricate relationships within the dataset, providing a nuanced understanding of risk factors and their implications for sustainable business practices. The results of our predictive modeling, illustrated through ROC curve analysis, underscore the effectiveness of our proposed approach in discerning potential loan defaults. This research not only addresses critical gaps in the existing literature but also provides a practical roadmap for organizations aiming to integrate sustainability into their risk management strategies.

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